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DESCRIPTION AND APPLICATION OF DUAL MASS DYNAMIC CONE PENETROMETER

by

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This report describes the dynamic cone penetrometer (DCP), its use, and the application of data obtained by its use. Procedures are presented for using the DCP to measure soil strength and correlating DCP index with CBR strength values required for operation of aircraft and military vehicles on unsurfaced soils. Procedures are also presented for using the DCP to evaluate aggregate surfaced roads and airfields for military operations based on the existing soil strength conditions.

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PREFACE

This report was prepared as a part of the work authorized by Headquarters, US Army Corps of Engineers, under Project AT40, Work Unit RC-003, "Soil Strength Determinations for Non-Paved Operating Surfaces."

The study that served as a basis for this report was conducted at the US Army Engineer Waterways Experiment Station (WES) from October 1989 through September 1990 by the Pavements Systems Division (PSD), Geotechnical Laboratory (GL). Personnel of the PSD involved in this study were Messrs. S. L. Webster, R. H. Grau, and T. P. Williams. This report was prepared by Messrs. Webster, Grau, and Williams.

This work was conducted under the general supervision of Dr. W. F. Marcuson III, Director, GL, and under the direct supervision of Mr. H. H. Ulery, Jr., former Chief, and Dr. G. M. Hammitt II, Chief, PSD, and Dr. A. J. Bush III, Chief, Criteria Development and Applications Branch, PSD.

At che time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
inches	2.54	centimetres
pounds (mass)	0.4535924	kilograms
square inches	6.4516	square centimetres

DESCRIPTION AND APPLICATION OF DUAL MASS DYNAMIC CONE PENETROMETER

PART I: INTRODUCTION

Background

1. From an engineering viewpoint, one of the most important properties which a soil possesses is shearing resistance or shear strength. A soil's shearing resistance under given conditions is related to its ability to withstand load. The shearing resistance is especially important in its relation to the supporting strength or bearing capacity of a soil used as a base or subgrade beneath a road, runway, or other structure. For most military pavement applications, the California Bearing Ratio (CBR) value of a soil is used as a measure of shear strength. The CBR is determined by a standardized penetration shear test and is used with empirical curves for designing and evaluating unsurfaced, aggregate surfaced, and flexible pavements for military roads and airfields. The CBR test is usually performed on laboratory-compacted test specimens when used in pavement design. When used in pavement evaluations, destructive test pits are usually dug to determine pavement layer thicknesses, and field in-place CBR tests are conducted on the base coarse, subbase, and subgrade materials. The in-place CBR tests are time-consuming to run and generally not practical for use in the theater of operations.

2. For unsurfaced roads and airfields, the airfield cone penetrometer is used to determine an index of soil strengths (Fenwick 1965) for various military load applications. The airfield penetrometer consists of a 30-deg* cone with a 0.2-sq-in. base area. The force required to penetrate to various depths in the soil is measured by a spring, and the airfield index is read directly from the penetrometer. The airfield cone penetrometer has a range of 0 to 15 (CBR value of 0 to approximately 18). The airfield cone penetrometer is compact, sturdy, and simple enough to be used by military personnel inexperienced in soil strength determination. A major drawback to the airfield cone

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

penetrometer is that it will not penetrate many crusts or thin base course layers that may lie over soft layers. Relying only on the surface airfield index test results under some conditions could result in the loss of vehicles or aircraft.

3. The dual mass dynamic cone penetrometer (DCP) described in this report will overcome some of the shortfalls associated with the CBR and airfield cone penetrometer. The DCP was originally designed and used for determining the strength profile of flexible pavement structures. It will penetrate soil layers having CBR strengths in excess of 100 and also measure soil strengths less than 1 CBR. The DCP is a powerful, relative compact, sturdy device that can be used by military personnel inexperienced in soil strength determination. The DCP described in this report is a modified version based on the DCP developed in South Africa and reported by Kleyn (1975) and Van Vuuren (1969).

Purpose and Scope

4. The purpose of this report is to describe the DCP, its use, and the application of data obtained by its use. Procedures are presented for using the DCP to measure soil strength and correlating DCP index with CBR strength values required for operation of aircraft and military vehicles on unsurfaced soils. Procedures are also presented for using the DCP to evaluate aggregate surfaced roads and airfields for military operations based on the existing soil strength conditions.

PART II: DESCRIPTION, USE, AND MAINTENANCE OF DCP

Description of Dual Mass DCP

Dual mass DCP device

5. The dual mass DCP as referred to in this report consists of a 5/8-in.-diam steel rod with a steel cone attached to one end which is driven into the pavement or subgrade by means of a sliding dual mass hammer (Figure 1). The angle of the cone is 60 deg and the diameter of the base of the cone is 0.790 in. The cone is hardened to increase service life. The diameter of the cone is 0.16 in. larger than that of the rod to ensure that the resistance to penetration is exerted on the cone. Figure 2 shows an assembled DCP with vertical scale for measuring the cone penetration depth. The DCP is driven into the soil by dropping either a 17.6 lb or 10.1 lb sliding hammer from a height of 22.6 in. The 17.6-lb hammer is converted to 10.1 lb by removing the hexagonal set screw and removing the outer steel sleeve as shown in Figure 3. This procedure can be accomplished during a test since the outer steel sleeve is designed to slide over the DCP handle. The cone penetration caused by one blow of the 17.6-lb hammer is essentially twice that caused by one blow of the 10.1-lb hammer. The 10.1-lb hammer is more suitable for use and yields better test results in weaker soils having a CBR values of 10 or less. The 17.6-lb hammer penetrates high strength soils quicker and may be preferred when these type soils are encountered. However, the 10.1-lb hammer can be used on soils up to CBR 80. The depth of cone penetration is measured at selected penetration or hammer drop intervals and the soil shear strength is reported in terms of DCP index. The DCP index is based on the average penetration depth resulting from one blow of the 17.6-lb hammer. The average penetration per hammer blow of the 10.1-lb hammer must be multiplied by 2 in order to obtain the DCP index value. The DCP is designed to penetrate soils to depths of 36 in. Individual DCP index values are reported for each test depth resulting in a soil-strength-with-depth profile for each test location.

Dual mass DCP kit

6. Figure 4 shows a dual mass DCP kit designed for Army engineer use. The kit includes the following items:

- a. Case assembly.
- b. Top rod threaded and welded to the handle.

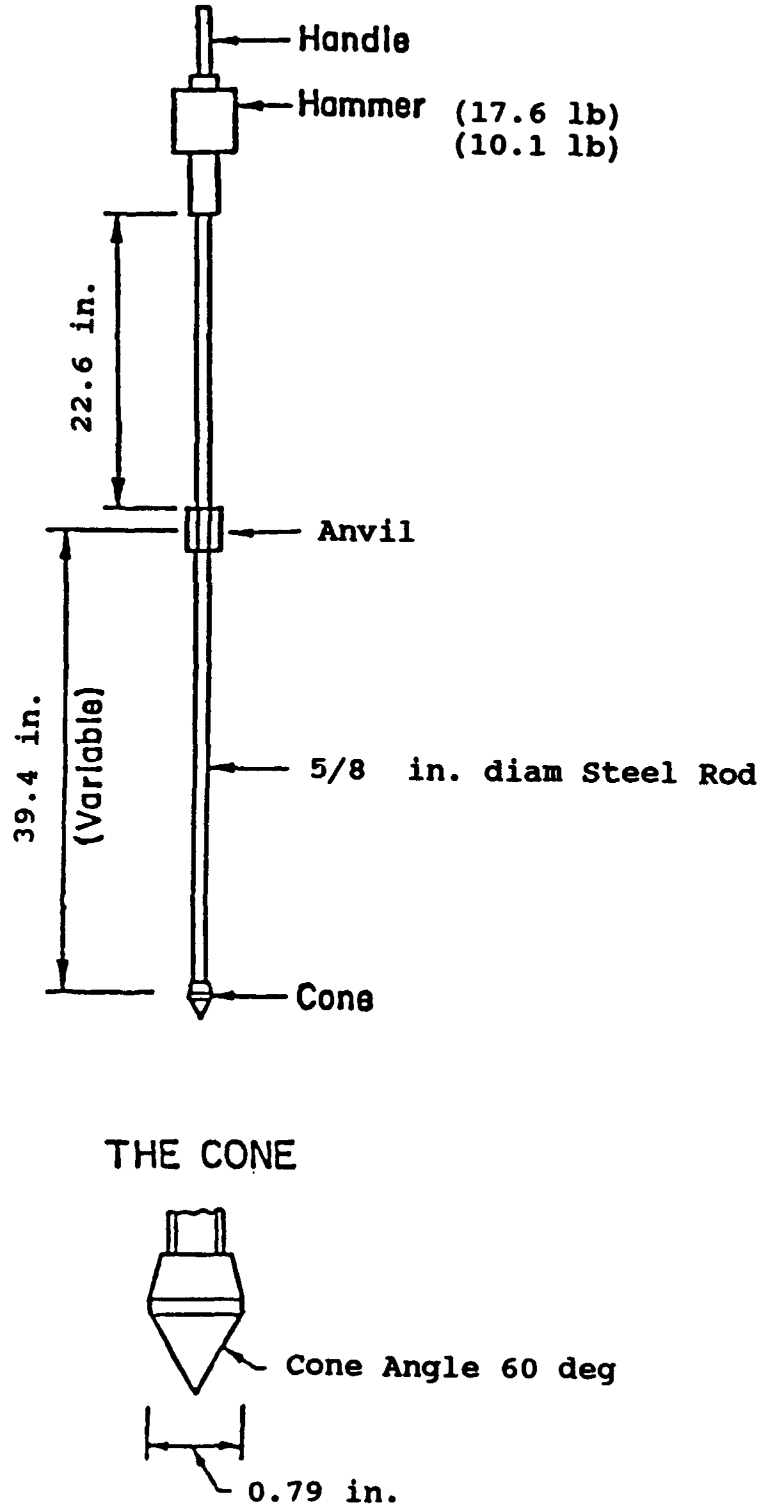

Figure 1. Dual mass DCP

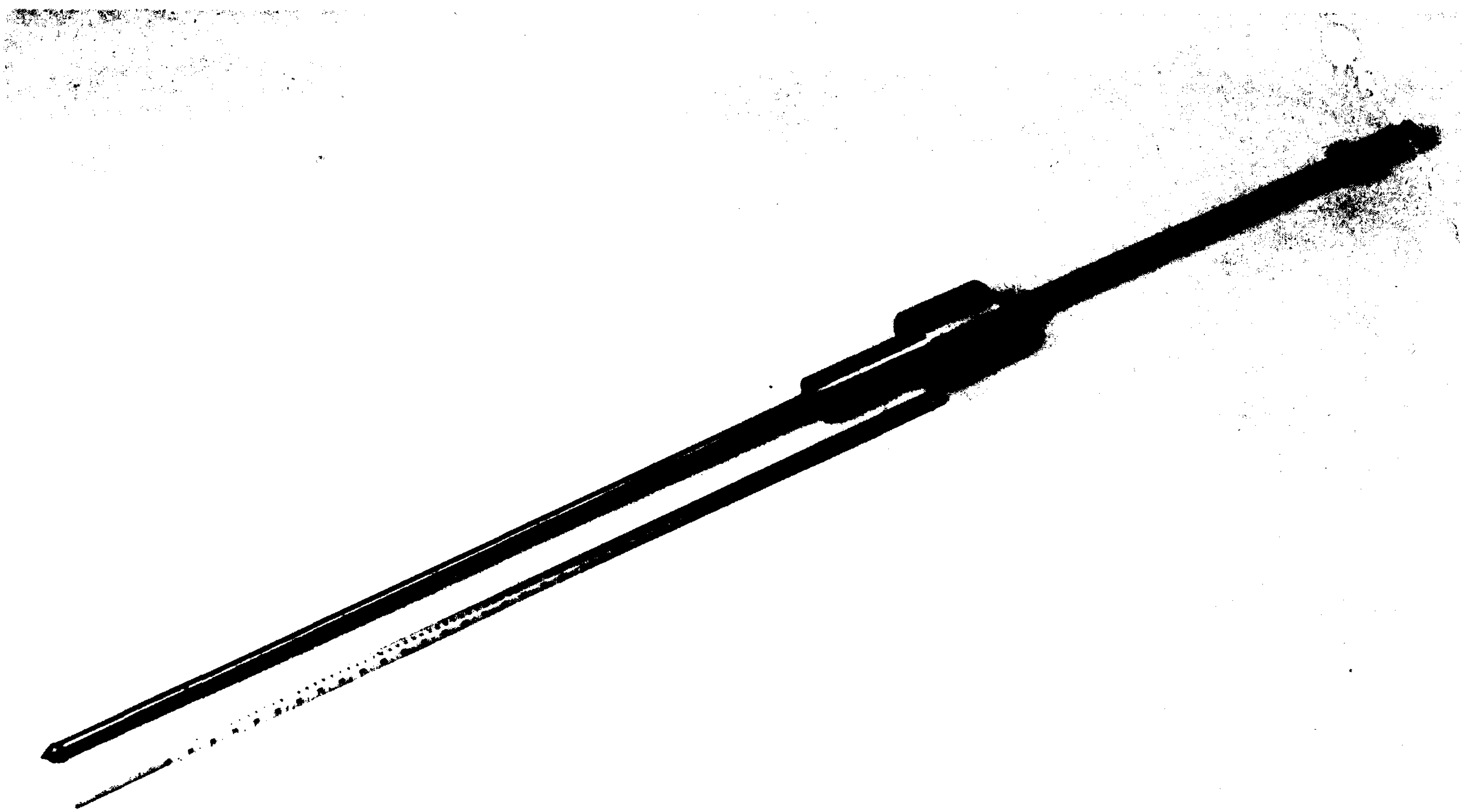

Figure 2. Assembled DCP with vertical scale

Figure 3. Dual mass hammer showing the removable steel sleeve, set screw, 10.1-lb hammer and 17.6-lb hammer configuration

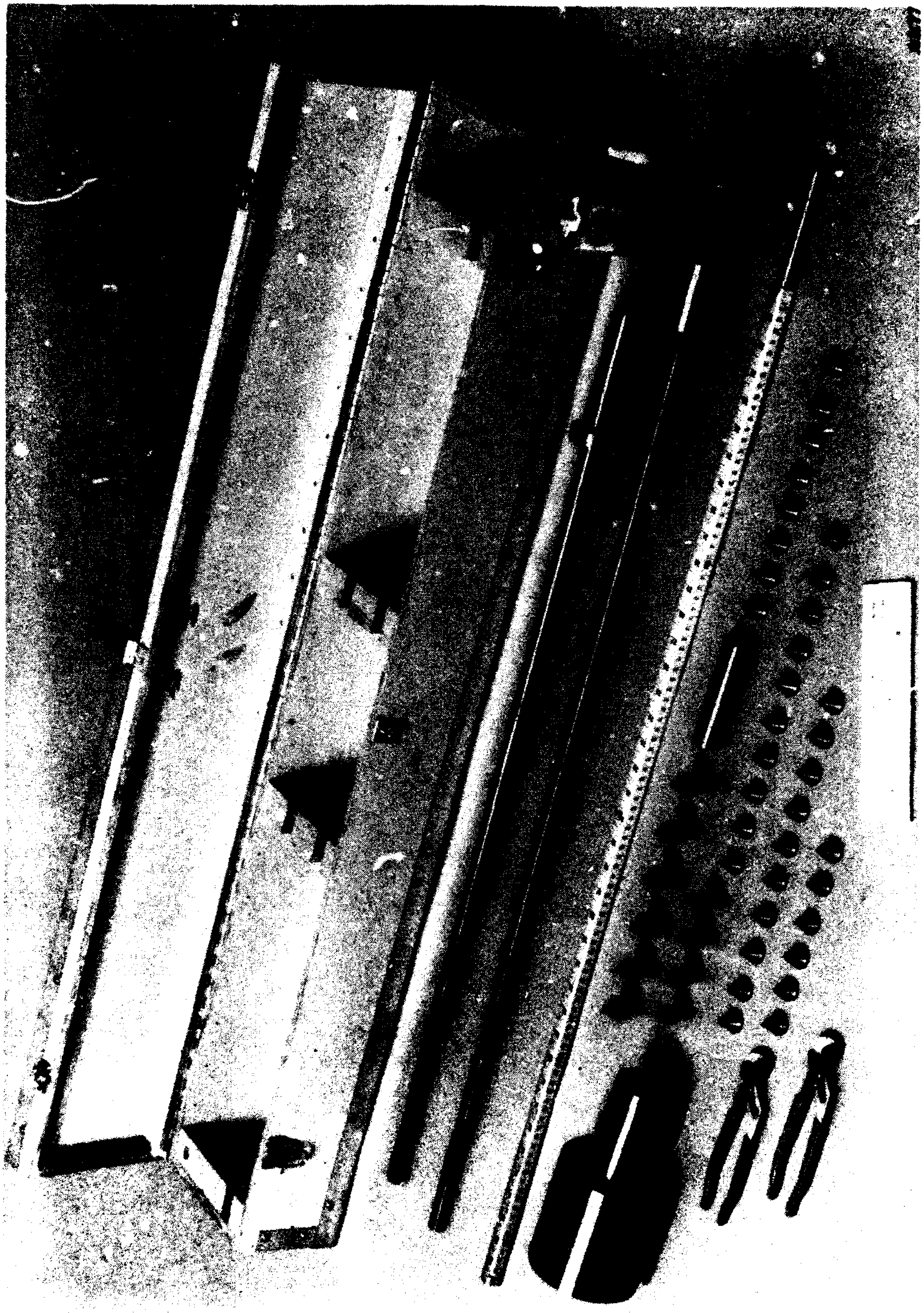

Figure 4. Dual mass DCP test kit

c. Bottom rod threaded and welded to the anvil.

d. Dual mass hammer.

e. Vertical scale in centimeters and inches.

f. Go-Nogo gage.

g. Six hardened 60-deg fixed cones.

h. Three hardened cone adapters and 200 disposable cones.

i. Two pair channel lock pliers.

j. One can 3-in-1 oil.

k. Loctite thread locking compound.

l. Hexagonal wrench set (5/64 to 1/4 in.).

Acquisition

7. The DCP test kit as shown in Figure 4 currently is not a Government stock item and is not available on the commercial market. Test kits and component parts are currently manufactured at the Waterways Experiment Station (WES) and are available to other Government agencies for cost reimbursement. A US patent on the DCP test kit has been applied for. Until a patent license with a commercial manufacturer can be obtained, the test kit will be available from WES or can be made by the user himself. A complete set of plans can be obtained by contacting Mr. Steve Webster (phone 601-624-2282) at WES.

Disposable cone

8. The disposable cone is for use in soils where the standard cone is difficult to remove. The disposable cone mounts on an adapter is shown in Figure 5. At the conclusion of the test, the disposable cone easily slides off the cone adapter allowing the operator to easily remove the DCP device from the soil. The disposable cone remains in the soil. Use of the disposable cone approximately doubles the number of tests per day that can be run by two operators.

Go-Nogo gage

9. The Go-Nogo gage is used to ensure that the cone base diameter is within proper tolerance. Each new cone should be checked before use and at selected usage intervals to ensure that the cone base diameter is within a proper tolerance of between 0.780 and 0.800 in. The cone must be replaced if its base diameter fits into both ends or neither end of the Go-Nogo gage. The cone is within proper tolerance when it fits into only one end of the gage.

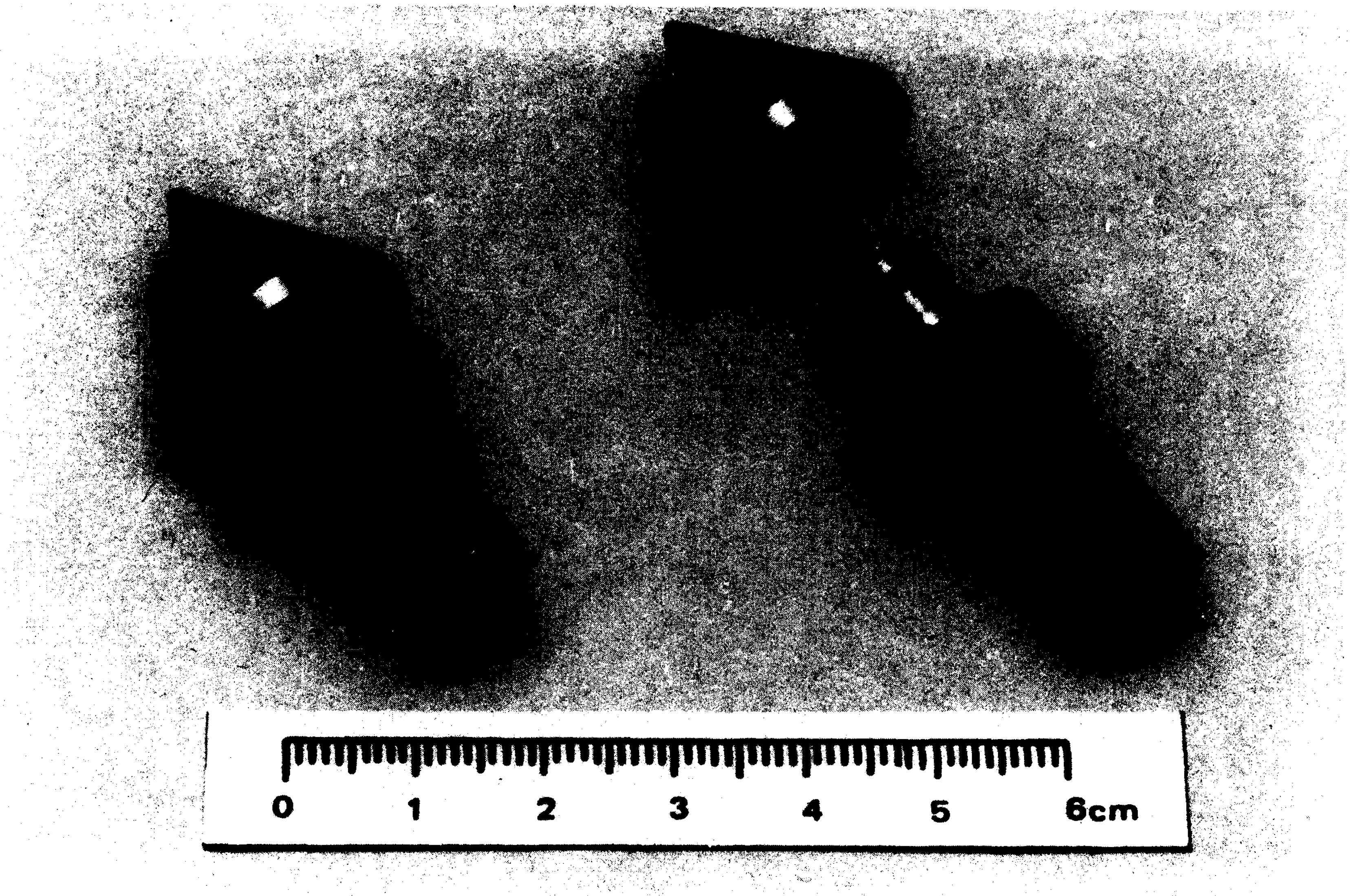

Figure 5. Disposable cone and adapter

10. The DCP test causes wear to the metal parts that make up the device. Parts of the DCP device will eventually suffer fatigue failure and will have to be repaired or replaced. In order to ensure maximum service life, the DCP should be inspected before it is used to ensure that all of the joints are tight. Thread locking compound should be used on loose joints. Also, the cone base diameter should be checked to ensure that it is within tolerance. If the cone point becomes bent or too blunt to penetrate around aggregate, it must be replaced.

11. Two people are required to operate the DCP. One person holds the device by its handle in a vertical position and taps the device using the hammer until the base of the cone is flush with the surface of the soil. The second person then checks the device for a zero reading by holding the vertical scale between the soil surface and bottom of the hammer. The bottom of the 4-in.-diam portion of the hammer should read zero millimetres on the vertical scale. In weak soils, the weight of the DCP device will sink the cone past its zero reading. In this case a zero blow penetration reading is recorded at the actual measured pretest depth in millimetres. The hammer is then raised to the bottom of the handle and dropped. Care should be exercised when raising the hammer to ensure that the hammer is touching the bottom of the handle but not lifting the cone before it is allowed to drop. The hammer must be allowed to fall freely with its downward movement not influenced by any hand movement. The operator should also be careful not to exert any downward force on the handle after dropping the hammer. Both the operator and the recorder should keep track of the number of hammer drops (blows) between measurements. The recorder is responsible for recording the number of hammer blows between measurements and measuring and recording the penetration after each set of hammer blows. The penetration measurements are recorded to the nearest 5 mm. As an example of how to read the penetration depth, Figure 6 shows a penetration depth of 150 mm.

12. The cone must penetrate a minimum of 25 mm between recorded measurements. Data taken at less than 25 mm penetration increments are unnecessary and sometimes result in inaccurate strength determinations. The number of hammer blows between measurement recordings will generally be 20, 10, 5, 3, 2, or 1 depending on the soil strength and thus cone penetration rate. Both

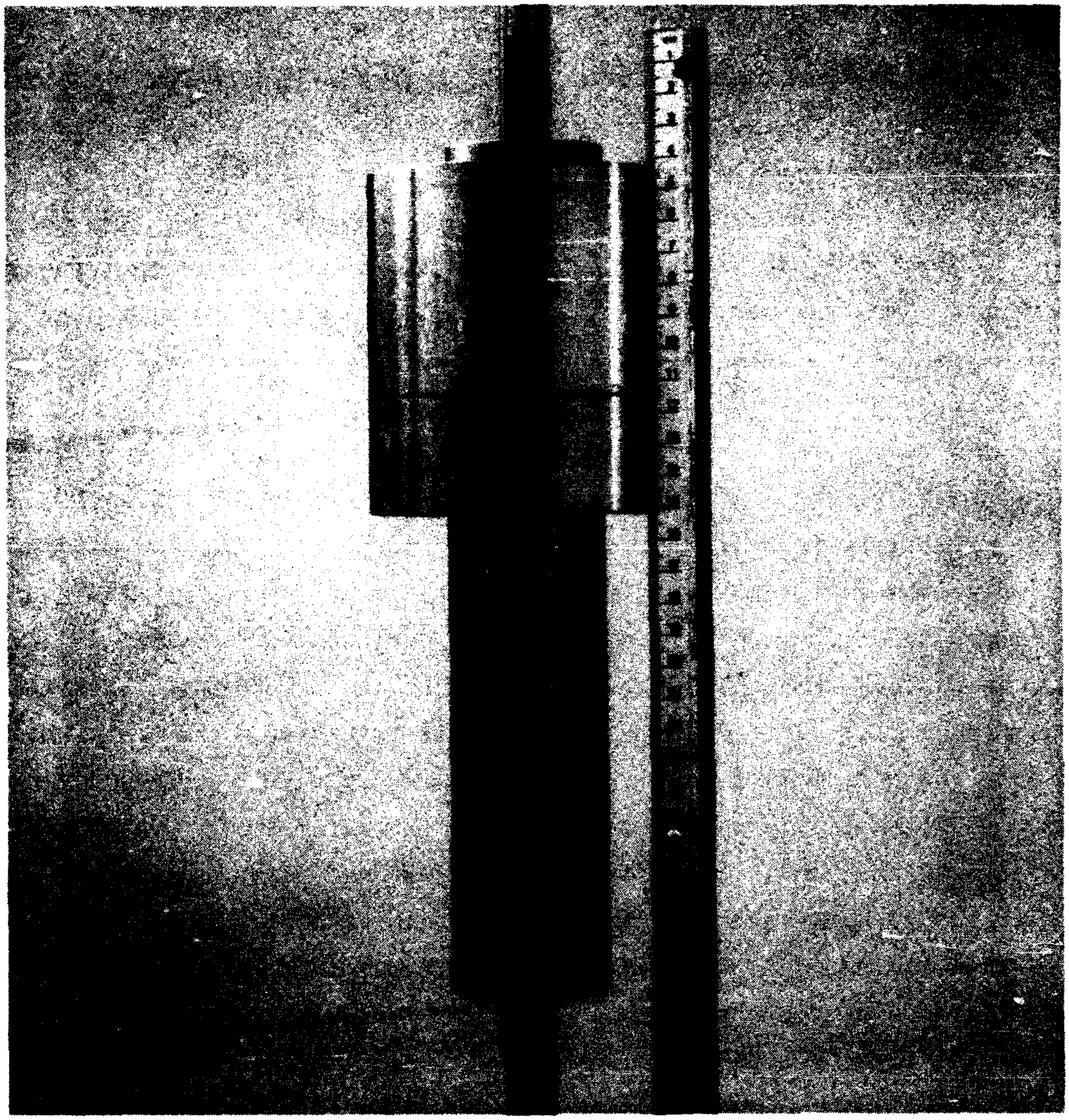

Figure 6. Example of penetration measurement showing a penetration of 150 mm

the operator and recorder should be alert to sudden increases in the cone penetration rates during the test. Any noticeable increase in the penetration rate indicates a weaker soil layer. The operator should stop and allow the recorder to record the blow count and penetration depth whenever a weaker soil layer is encountered.

13. After the cone has been driven to the desired test depth (maximum 39 in.), it is extracted from the soil by driving the hammer against the top handle. Caution must be exercised during this operation in order not to damage the DCP device. The hammer must be raised in a vertical direction (rather than in an arcing motion) or the rod may be bent or broken where it connects to the anvil. In soils where great difficulty is encountered in extracting the DCP device, the disposable cones should be used. Use of the disposable cones will save wear and tear on both the device and operator. In some soils with large aggregate the DCP may try to penetrate the soil at a slant rather than from a vertical direction. The operator should not apply force to the handle of the DCP in an attempt to force it to penetrate the soil vertically. Lateral force on the handle in an attempt to make the DCP penetrate the soil vertically will cause the upper handle rod to fatigue and break at the point where it screws into the anvil. Instead, the test should be stopped when the handle deviates laterally 6 in. or more from the vertical position and a new test attempted at another location.

DCP Maintenance

14. The DCP should be kept clean and all soil removed from the penetration rod and cone before each test. A light application of spray lubricant or oil should be applied to the hammer slide rod before each days use. All joints should be constantly monitored and kept tight. Loose joints will lead to equipment failure. Any problem joints should be treated with a joint locking compound. The lower penetration rod should be kept clean and lubricated with oil when clay soils are tested.

PART III: SOIL STRENGTH EVALUATIONS WITH DCP

Number of Measurements

15. The number of measurements to be made, the location of the measurements, depth of measurements required, and frequency of recording data with depth vary with type of road or airfield pavement operation and with time available for conducting the tests. For this reason, hard and fast rules for the number of tests required in evaluating roads and airfields are not practicable. Soil conditions are extremely variable. The strength range and uniformity of the soils or existing pavement materials will generally control the number of measurements necessary. In all cases, it is advisable to test those spots that appear to be weakest first, since the weakest condition controls the pavement evaluation. Penetrations in areas that appear to be firm and uniform may be few and widely spaced. In areas of doubtful strength, the penetration tests should be more closely spaced. No less than three penetration tests should be made in each area having similar type soil conditions.

Reading Depths in Soil

16. Soil strength usually increases with depth, but in some cases a thin, hard crust will overlay a soft layer or the soil will contain thin layers of hard and soft material. For this reason and the fact that many aircraft and some military vehicles will effect the soil to depths of 36 in. or more, it is recommended that each penetration be made to a depth of 36 in. unless prevented by a very hard condition at a lesser depth. Soil test depths may be reduced when required traffic operations are known and the thickness requirements indicate that a reduced thickness above the subgrade controls the evaluation.

Correlation of DCP Index with CBR

17. Correlation of DCP index with CBR is necessary since the CBR is the soil strength value used for designing and evaluating unsurfaced, aggregate surfaced and flexible pavements for military roads and airfields. A data base of field CBR versus DCP index values was collected by WES technicians from

many sites and different soil types (Table A1). In addition, correlation test results by Harison (1987), Kleyn (1975), Livneh and Ishai (1987), and Van Vuuren (1969) were compared with the data base test values (Figure A1). General agreement was found between the various sources of information. The equation Log CBR = 2.46 - 1.12(Log DCP) was selected as the best correlation. In this equation DCP is the penetration ratio in millimetres per blow for the 17.6-lb hammer. Figure 7 shows a plot of the correlation of CBR versus DCP index. Figure 8 shows a tabulated correlation of DCP index with CBR.

Data Tabulation

18. A suggested format for DCP data collection is shown in Figure 9. The data can be tabulated in spreadsheet format with the only data input values required being that of the number of hammer blows, hammer weight, and cone penetration recorded to the nearest 5 mm after each set of hammer blows. Figure 10 shows a filled-in example of a DCP data sheet

Data Analysis

19. The user should group test data for locations having similar type soil conditions. For each location group, an individual should make a combined data plot showing CBR, interpreted from Figure 7, versus depth in inches as shown in Figure 11. From this data an average data plot of CBR versus depth in inches should be developed. The average data plots for each location having similar type soil conditions are used in the following pavement evaluations.

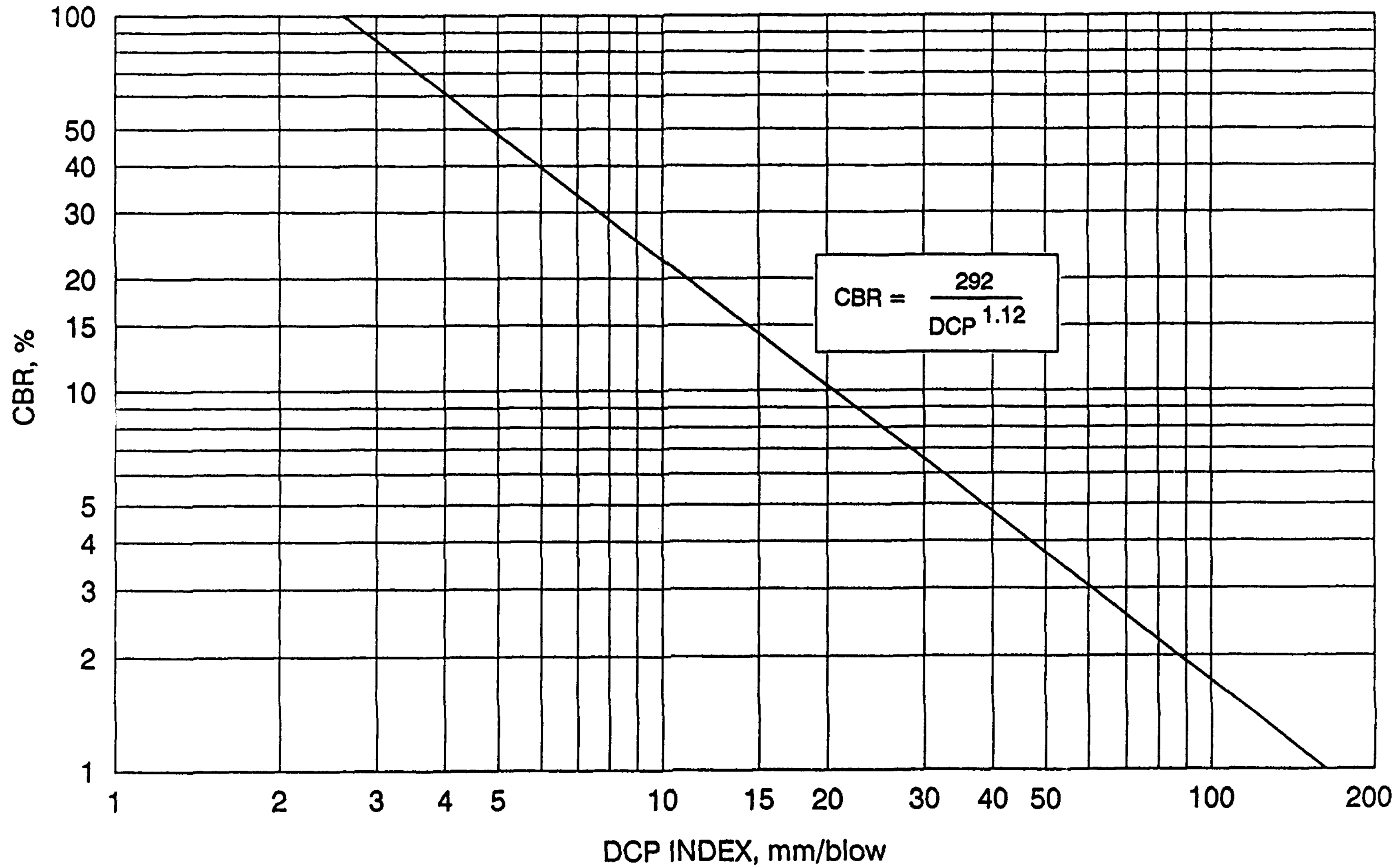

Figure 7. Correlation plot of CBR versus DCP index

DCP Index mm/blow	CBR %	DCP Index mm/blow	CBR %
<3	100	51	3.6
3	80	52	3.5
4	60	53-54	3.4
5	50	55	3.3
6	40	56-57	3.2
7	35	58	3.1
8	30	59-60	3.0
9	25	61-62	2.9
10-11	20	63-64	2.8
12	18	65-66	2.7
13	16	67-68	2.6
14	15	69-71	2.5
15	14	72-74	2.4
16	13	75-77	2.3
17	12	78-80	2.2
18-19	11	81-83	2.1
20-21	10	84-87	2.0
22-23	9	88-91	1.9
24-26	8	92-96	1.8
27-29	7	97-101	1.7
30-34	6	102-107	1.6
35-38	5	108-114	1.5
39	4.8	115-121	1.4
40	4.7	122-130	1.3
41	4.6	131-140	1.2
42	4.4	141-152	1.1
43	4.3	153-166	1.0
44	4.2	166-183	0.9
45	4.1	184-205	0.8
46	4.0	206-233	0.7
47	3.9	234-271	0.6
48	3.8	272-324	0.5
49-50	3.7	>324	<0.5

Figure 8. Tabulated correlation of CBR versus DCP index

DCP DATA SHEET

Project ______________________ Date ______________________

Location ______________________ Soil Type(s) ______________________

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
0		—	—	—	—	—	0

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetration between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From CBR versus DCP correlation
(8) Previous entry in (2) divided by 25.4 rounded off to .1 in.

Figure 9. Example of DCP data sheet

DCP DATA SHEET

Project FOREST SERVICE RD Date 24 SEPT 90

Location STA 30+50, 4 FT RT OF C/L Soil Type(s) GW/CL

No. of Blows (1)	Accumulative Penetration mm (2)	Penetration per Blow Set mm (3)	Penetration per Blow mm (4)	Hammer Blow Factor (5)	DCP Index (6)	CBR % (7)	Depth in. (8)
0	0	—	—	—	—	—	0
5	25	25	5.0	1	5.0	50	1.0
5	55	30	6.0	1	6.0	40	2.2
15	125	70	4.7	1	4.7	50	4.9
10	175	50	5.0	1	5.0	50	6.9
5	205	30	6.0	1	6.0	40	8.1
5	230	25	5.0	1	5.0	50	9.1
10	280	50	5.0	1	5.0	50	11.0
5	310	30	6.0	1	6.0	40	12.2
5	340	30	6.0	1	6.0	40	13.4
5	375	35	7.0	1	7.0	35	14.8
5	435	60	12.0	1	12.0	18	17.1
2	495	60	30.0	1	30.0	6	19.5
2	530	35	17.5	1	17.5	12	20.9
3	555	25	8.3	1	8.3	30	21.9
6	605	50	12.5	1	12.5	18	23.8
3	640	35	11.7	1	11.7	18	25.2
3	680	40	13.3	1	13.3	16	26.8
3	705	25	8.3	1	8.3	30	27.8
3	745	40	13.3	1	13.3	16	29.3
3	775	30	10.0	1	10.0	20	30.5
3	810	35	11.7	1	11.7	18	31.9
3	840	30	10.0	1	10.0	20	33.1
3	865	25	8.3	1	8.3	30	34.1
4	890	25	6.3	1	6.3	40	35.0
4	920	30	7.5	1	7.5	35	36.2

(1) No. of hammer blows between test readings
(2) Accumulative cone penetration after each set of hammer blows
(Minimum penetfation between test readings should be 25 mm)
(3) Difference in accumulative penetration (2) at start and end of hammer blow set
(4) (3) divided by (1)
(5) Enter 1 for 17.6 lb hammer; 2 for 10.1 lb hammer
(6) (4) X (5)
(7) From CBR versus DCP correlation
(8) Previous entry in (2) divided by 25.4 rounded off to .1 in.

Figure 10. Example of completed DCP data sheet

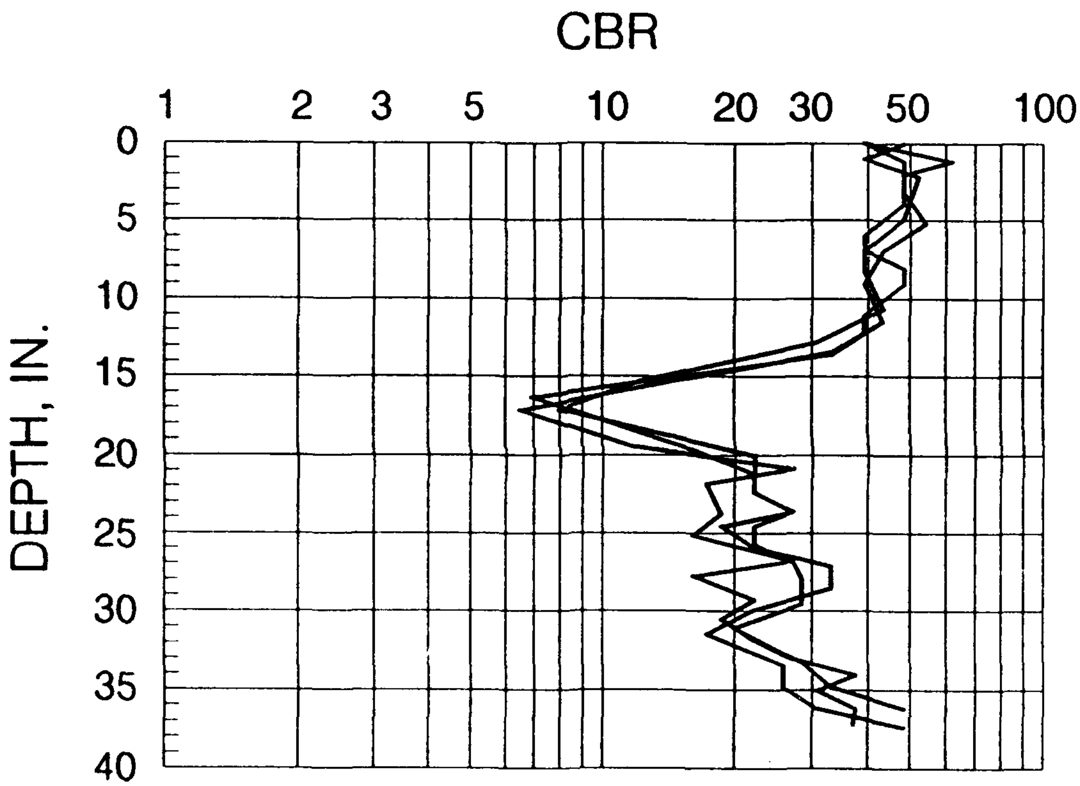

Figure 11. Example of DCP data plot for three tests in similar type soils

PART IV: APPLICATION OF DCP DATA

Evaluation of Unsurfaced Soils and Aggregate Surfaced Roads and Airfields

20. Army Technical Manual TM 5-822-12 "Design of Aggregate Surfaced Roads and Airfields" (Appendix B) can be used for evaluating the potential of military operations on unsurfaced soils and aggregate surfaced roads and airfields based on the existing soil conditions. The evaluation procedure is the reverse of the design procedure. CBR and thickness evaluation data from the DCP tests are used to enter the appropriate set of design curves in Figures 1 through 4 of TM 5-822-12 to determine the allowable design index for roads or allowable gross weight and aircraft pass configuration for airfields. The design index for roads is then used to determine the allowable road class and number of vehicle passes per day for various traffic categories. In using Figures 2 through 4 of TM 5-822-12, a "Class I" airfield is for rotary- and fixed-wing aircraft with maximum gross weight of 30,000 lb or less, a "Class II" airfield is for rotary-wing aircraft with maximum gross weights greater than 30,000 lb, and a "Class III" airfield is for fixed-wing aircraft with maximum gross weights greater than 30,000 lb.

21. For unsurfaced soils in which the soil strength increases with depth, the average strength of the top layer is first used in order to make sure that compaction to a higher strength or the addition of a surfacing aggregate layer is not required. If the top layer of soil is adequate to support the desired design index or aircraft passes, then the strength of weaker soil layers beneath the top layer is used in order to check for adequate thickness requirements of the surfacing layers of soil.

22. For aggregate surfaced roads and airfields, both the subgrade soil strength and aggregate layer strength should be used to ensure that the aggregate thickness and strength requirements are adequate for a given design index or aircraft pass level.

Special Considerations

Weather

23. Because soil conditions are immediately and significantly affected by weather, an evaluation is valid only for the period immediately after measurements are made for unsurfaced pavements. However, it usually may be assumed that the evaluation will remain constant as long as no rain occurs. Gravel surfaced pavements will be affected to a much lesser extent by rain.

Clay soils

24. DCP tests in highly plastic clays are generally accurate for depths to approximately 12 in. At deeper depths, clay sticking to the lower rod may indicate higher CBR values than the actual values. Oiling the penetration rod will help in preventing the clay from sticking to the penetration rod, however, it will not significantly improve the test results. A 2-in.-diam (or larger) auger can be used to open the test hole up after each 12 in. DCP test penetration. This will eliminate clay-lower rod friction problems and allow the test to accurately measure the clay soil strength for an additional 12 in.

Sands

25. Many sands occur in a loose state. Such sands when relatively dry will show no DCP index values for the top few inches and then may show increasing DCP index values with depth. The confining action of aircraft tires will increase the strength of the sand. Generally, any dry sand or gravel will be adequate for aircraft in the C-130 class, regardless of the DCP index values. All sands and gravels in a "quick" condition (water percolating through them) must be avoided. Evaluation of moist sands should be based on the DCP tests as described earlier.

Soil remolding

26. Soil remolding is the changing or working of a soil by traffic. The effects of traffic remolding may have a beneficial, neutral, or detrimental effect, resulting in a change of soil strength. Additional DCP tests should be run after some traffic has been applied to determine any changes that may have occurred in soil strengths.

Cone penetration refusal

27. If the cone does not penetrate 25 mm after 10 blows with the 17.6-lb hammer (20 blows with the 10.1-lb hammer), the test should be stopped. If this firm material is a stabilized soil or high strength aggregate base

layer, it should be cored or auger drilled to allow access of the DCP cone to underling layers. The DCP test can then proceed through the access hole after the depth of the material layer has been recorded. The material layer is assigned a CBR value of 100 plus. However, if a core or auger drill is not available, the 17.6-lb DCP hammer can usually be used to drive the lower rod and cone through the firm material. If the cone penetration was stopped by a large rock or other object, the DCP should be extracted and another attempt made within a few feet of the initial test. The DCP is generally not suitable for soils having significant amounts of aggregate greater than a 2-in.-sieve size.

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APPENDIX A: WES FIELD DATA FOR CBR VERSUS DCP INDEX

Table A1

CBR Versus DCP

CBR %	DCP Index mm/blow	Soil Type
62	3	SW
88	3	SM-SC
100	3	SM-SC
38	3	
40	4	SC
46	5	SW
38	5	SW
52	5	SW
34	6	SW
29	6	SP-SM
27	6	
33	7	SW
53	7	SP-SM
27	7	CL
16	7	SP-SM
30	7	
44	7	SW
38	7	
18	8	CL
22	8	CL
39	8	SW
25	8	SC
22	9	CL
20	9	SW
21	10	SW
32	10	SW
21	10	SW
47	10	SW
8	10	CL
15	10	CL
10	11	CL
20	11	CL
32	11	SW
19	11	
46	11	SC
19	12	CL
24	12	SW
16	12	CL
12	12	CL
16	12	GC
25	12	CL
32	13	SW

(Continued)

(Sheet 1 of 3)

Table A1 (Continued)

CBR %	DCP Index mm/blow	Soil Type
19	13	CL
25	13	CL
17	13	SW
16	13	CL
31	13	CL
16	14	CL
17	14	CL
12	14	CL
25	14	SW
15	15	CL
12	15	
10	15	CL
10	15	CL
17	15	CL
15	15	CL
21	15	CL
16	16	CL
18	16	CL
22	16	SW
16	16	CL
18	16	CL
14	16	CL
23	17	SW
11	17	SP-SM
14	17	CL
18	17	CL
16	17	SW
22	17	CL
15	17	CL
7	17	CL
22	18	SW
13	18	CL
18	18	CL
12	18	CL
7	18	CL
10	18	CL
4	19	
12	19	
4	19	CL
6	20	
9	20	SP-SM
6	22	CL
11	22	CL
13	23	CL
6	23	CL

(Continued)

(Sheet 2 of 3)

Table A1 (Concluded)

CBR %	DCP Index mm/blow	Soil Type
7	24	CL
10	24	CL
8	24	CL
3	26	CL
8	26	CL
6	29	CL
7	30	CL
8	30	CL
7	30	CL
14	32	CL
3	35	CL
11	40	CH
7	40	CH
7	41	CH
9	42	CH
9	44	CH
9	45	CH
9	48	CH
4	48	CH
9	49	CH
4	51	CH
3	53	CH
5	62	CH
3.8	65	CH
5	65	CH
4.9	67	CH
4	69	CH
4.8	83	CH
3	111	CH

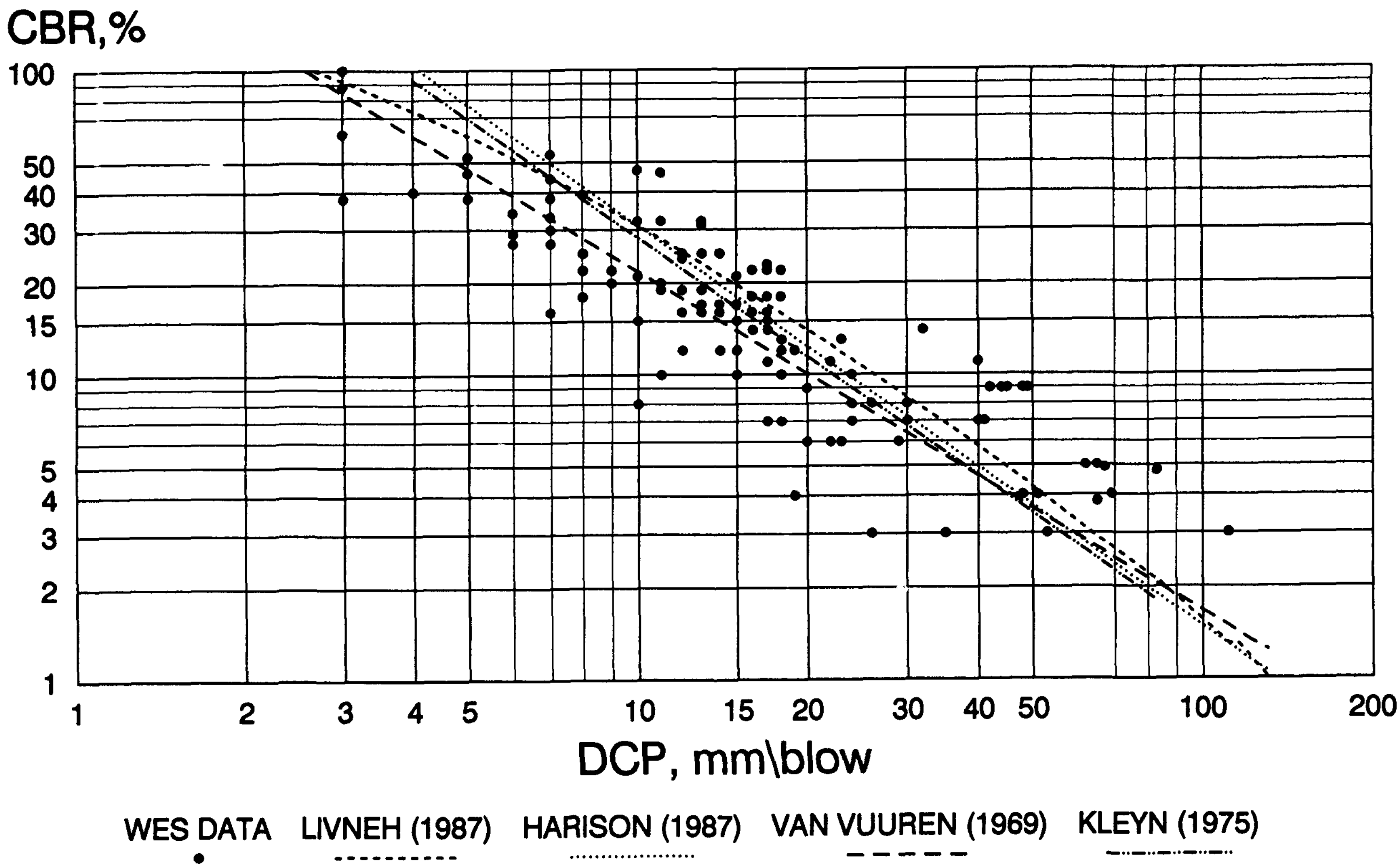


Figure A1. DCP versus CBR

APPENDIX B: DESIGN OF AGGREGATE SURFACED ROADS AND AIRFIELDS

TECHNICAL MANUAL

No. 5-822-12

HEADQUARTERS
DEPARTMENT OF THE ARMY
Washington, DC, *28 September 1990*

DESIGN OF AGGREGATE SURFACED ROADS AND AIRFIELDS

Approved for public release; distribution is unlimited

LIST OF TABLES

DESIGN OF AGGREGATE SURFACED ROADS AND AIRFIELDS

1. Purpose

This manual presents the procedures for design of aggregate surfaced roads and airfields.

2. Scope

This manual presents criteria for determining the thickness, material, and compaction requirements for all classes of aggregate surfaced roads and for Class I, II, and III airfields at US Army installations. Road classes are defined in TM 5-822-2, and airfield classes are defined in TM 5-803-4. Class IV Army airfields would normally be paved. Use of the term roads includes roads, streets, open storage areas, and parking areas. Use of the term airfields includes heliports, runways, taxiways, and parking aprons. Design requirements are presented for frost and nonfrost areas.

3. References

Publications cited in this manual are listed in appendix A.

4. Design of aggregate surfaced roads

a. Procedures. The thickness design of aggregate surfaced roads is similar to the design of flexible pavement roads as contained in TM 5-822-5. This procedure involves assigning a class to the road being designed based upon the number of vehicles per day. A design category is then assigned to the traffic from which a design index is determined. This design index is used with figure 1 to select the thickness (minimum of 4 inches) of aggregate required above a soil with a given strength expressed in terms of California Bearing Ratio (CBR) for nonfrost areas or in terms of a frost area soil support index (FASSI) in frost areas.

b. Classes of roads. The classes of aggregate surfaced roads vary from A to G. Selection of the proper class depends upon the traffic intensity and is determined from table 1.

c. Design index. The design of gravel roads will be based on a design index, which is an index representing all traffic expected to use the road during its life. The design index is based on typical magnitudes and compositions of traffic reduced to equivalents in terms of repetitions of an 18,000-pound single-axle, dual-wheel load. For designs involving rubber-tired vehicles, traffic is classified in three groups as follows:

Group 1. Passenger cars and panel and pickup trucks.

Group 2. Two-axle trucks.

Group 3. Three-, four-, and five-axle trucks.

Traffic composition will then be grouped in the following categories:

Category I. Traffic composed primarily of passenger cars, panel and pickup trucks (Group 1 vehicles), and containing not more than 1 percent two-axle trucks (Group 2 vehicles).

Category II. Traffic composed primarily of passenger cars, panel and pickup trucks (Group 1 vehicles), and containing as much as 10 percent two-axle trucks (Group 2 vehicles). No trucks having three or more axles (Group 3 vehicles) are permitted in this category.

Category III. Traffic containing as much as 15 percent trucks, but with not more than 1 percent of the total traffic composed of trucks having three or more axles (Group 3 vehicles).

Category IV. Traffic containing as much as 25 percent trucks, but with not more than 10 percent of the total traffic composed of trucks having three or more axles (Group 3 vehicles).

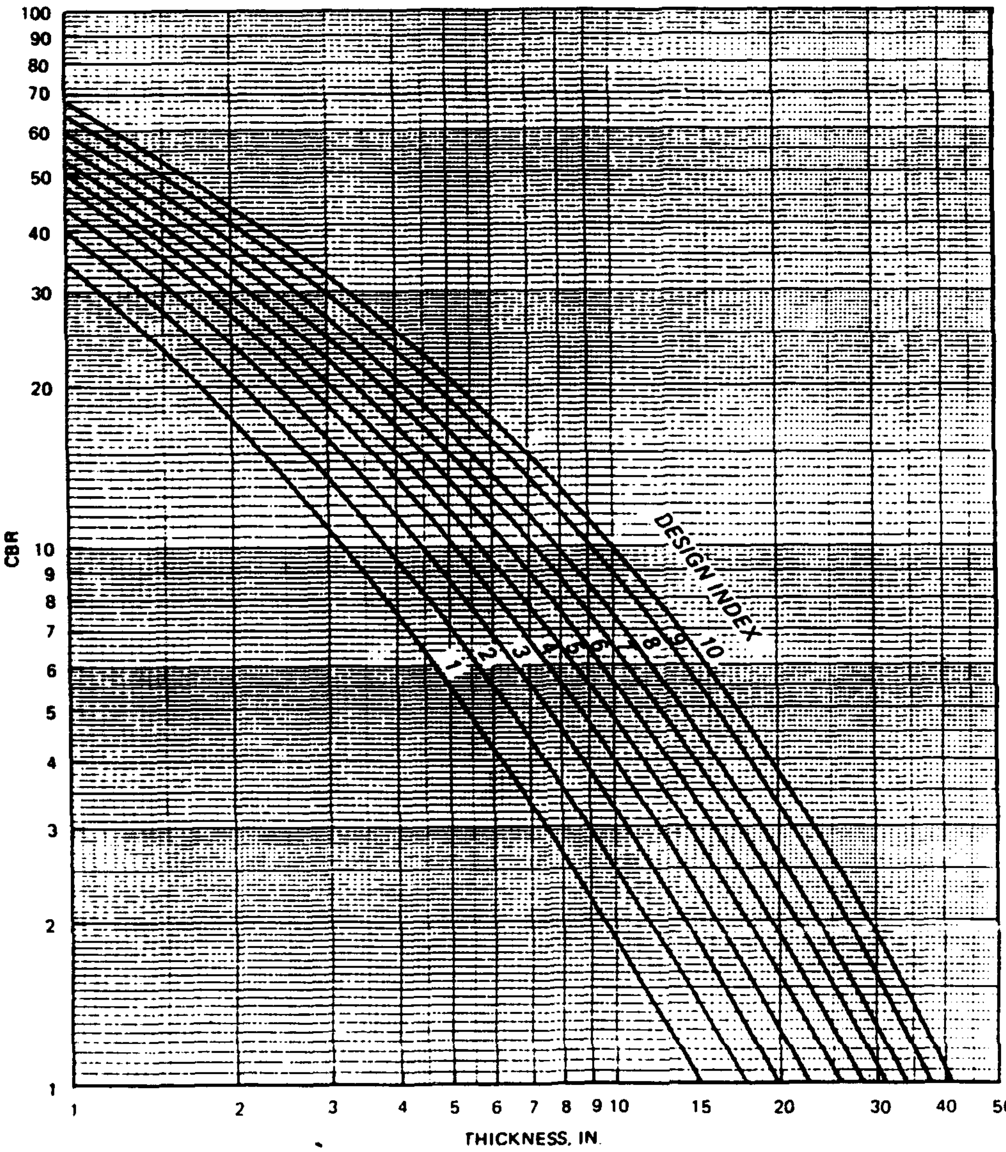
Category IVA. Traffic containing more than 25 percent trucks or more than 10 percent trucks having three or more axles (Group 3 vehicles).

d. Tracked vehicles and forklift trucks. Tracked vehicles having gross weights not exceeding 15,000 pounds and forklift trucks having gross weights not exceeding 6,000 pounds may be treated as two-axle trucks (Group 2 vehicles) in determining the design index. Tracked vehicles having gross weights exceeding 15,000 pounds but not 40,000 pounds and forklift trucks having gross weights exceeding 6,000 pounds but not 10,000 pounds may be treated as Group 3 vehicles in determining the design index. Traffic composed of tracked vehicles exceeding 40,000-pound gross weight and forklift trucks exceeding 10,000-pound gross weight has been divided into the following three categories:

Maximum Vehicle Gross Weight, pounds

Category	Tracked Vehicles	Forklift Trucks
V	60,000	15,000
VI	90,000	20,000
VII	120,000	35,000

e. Design index. The design index to be used in designing a gravel road for the usual pneumatic-tired vehicles will be selected from table 2.



DESIGN CURVES FOR
GRAVEL SURFACED ROADS

Figure 1. Thickness design curves for aggregate surfaced roads.

f. Roads for tracked vehicles. Roads sustaining traffic of tracked vehicles weighing less than 40,000 pounds, and forklift trucks weighing less than 10,000 pounds, will be designed in accordance with the pertinent class and category from table 2. Roads sustaining traffic of tracked vehicles, heavier than 40,000 pounds, and forklift trucks heavier than 10,000 pounds, will be designed in accordance with the traffic intensity and category from table 3.

g. Design life. The life assumed for design is 25 years. For a design life less than 5 years, the design indexes in tables 2 and 3 may be reduced by one. Design indexes below three should not be reduced.

h. Entrances, exits, and segments. Regardless of the design class selected for hardstands, special consideration should be given to the design of approach roads, exit roads, and other heavily trafficked areas. Failure or poor performance in these channelized traffic areas

Table 1. Criteria for selecting aggregate surface road class

Road Class	Number of Vehicles per day
A	10,000
B	8,400 - 10,000
C	6,300 - 8,400
D	2,100 - 6,300
E	210 - 2,100
F	70 - 210
G	under 70

Table 2. Design index for pneumatic-tired vehicles.

	Design Index			
Class	Category I	Category II	Category III	Category IV
A	3	4	5	6
B	3	4	5	6
C	3	4	4	6
D	2	3	4	5
E	1	2	3	4
F	1	1	2	3
G	1	1	1	2

Table 3. Design index for tracked vehicles and forklift trucks.

	Number of Vehicles per Day (or Week as indicated)							
Traffic Category	500	200	100	40	10	4	1	1 Per Week
V	8	7	6	6	5	5	5	—
VI	—	9	8	8	7	6	6	5
VII	—	—	10	10	9	8	7	6

often has greater impact than localized failure on the hardstand itself. Since these areas will almost certainly be subjected to more frequent and heavier loads than the hardstand, the design index used for the primary road should be used for entrances and exits to the hardstand. In the case of large hardstands having multiple use and multiple entrances and exits, consideration should be given to partitioning and using different classes of design. The immediate benefits that would accrue include economy through elimination of overdesign in some areas and better organization of vehicles and equipment.

i. Thickness criteria (nonfrost areas). Thickness requirements for aggregate surfaced roads are determined from figure 1 for a given soil strength and design index. The minimum thickness requirement will be 4 inches. Figure 1 will be entered with the CBR of the subgrade to determine the thickness of aggregate required for the appropriate design index. The thickness determined from the figure may be constructed of compacted granular fill for the total depth over the natural subgrade or in a layered system of granular fill (including subbases) and compacted subgrade for the same total depth. The layered section should be checked to ensure that an adequate thickness of material is used to protect the underlying layer based on the CBR of the underlying layer. The granular fill may consist of base and subbase material provided the top 6 inches meet the gradation requirements in paragraph 8.

5. Design of aggregate surfaced airfields

The thickness design of aggregate surfaced airfields is similar to the design of flexible pavement airfields as contained in TM 5-825-2. This procedure involves assigning a class to the airfield based upon the aircraft controlling the design. Having selected the class of airfield, the design is accomplished using figures 2 through 4.

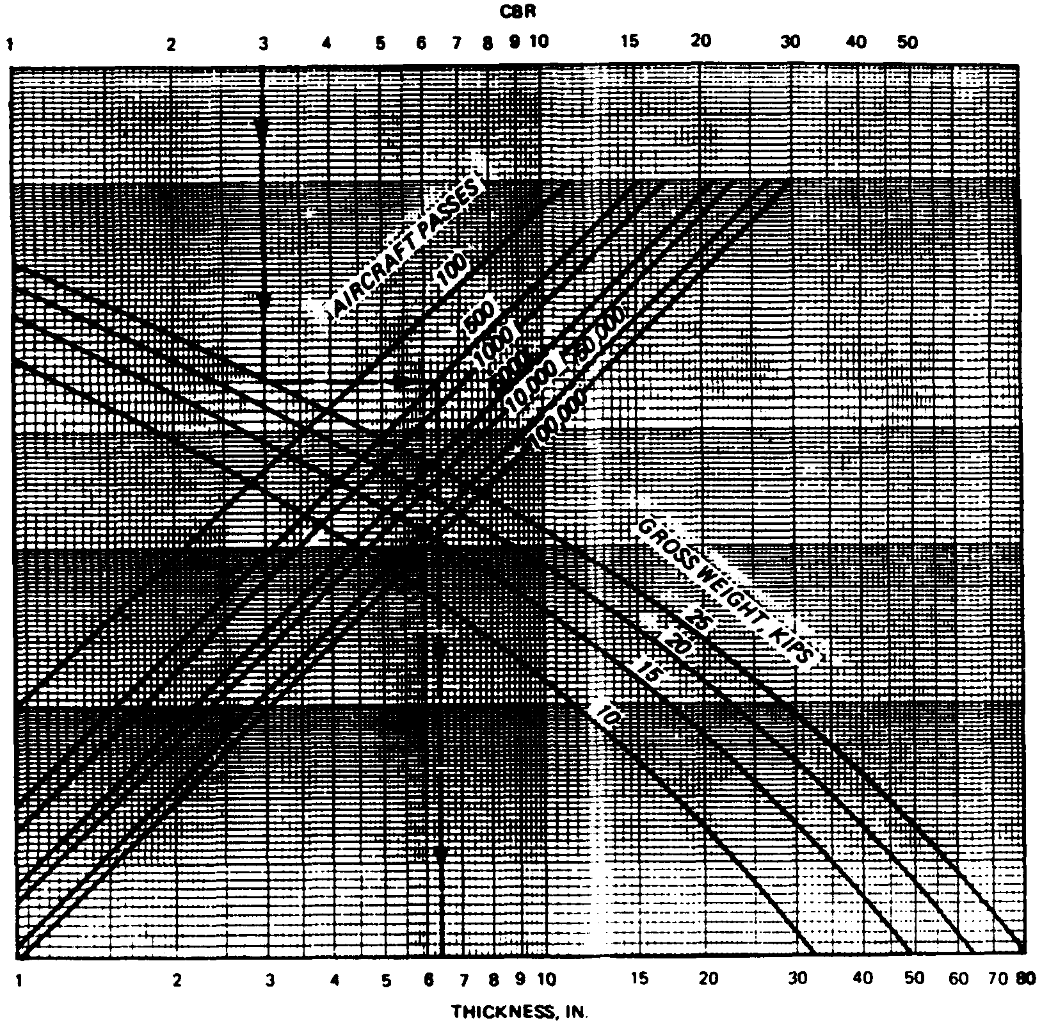
a. Classes of airfields. There are four classes of Army airfields. These are Classes I–IV, although only Classes I–III are considered candidates for aggregate surfacing. Each class of airfield is designed for a standard loading condition and pass level as defined in TM 5-803-4. Where necessary, airfields may be designed for loads and pass levels other than the standard, and the criteria herein provide thicknesses for varying pass and load levels.

b. Traffic areas. Army airfields are divided into traffic areas for design purposes. Type B traffic areas consist of taxiways, the first 1,000 feet of runway ends, and aprons. Type C traffic areas are the interior portions of the runway (between the 1,000 foot runway ends).

c. Thickness criteria (nonfrost areas). Thickness requirements for aggregate surfaced airfields are determined from figures 2 through 4 for types B and C traffic areas. Thicknesses for type B areas are determined directly from the curves, and type C traffic areas are designed using 75 percent of the load used to design type B traffic areas. The minimum thickness requirement for all cases will be 4 inches. The figure for the appropriate airfield class will be entered with the subgrade CBR to determine the thickness required for a given load and pass level. The thickness determined from the figure may be constructed of compacted granular fill for the total depth over the natural subgrade or in a layered system of granular fill and compacted subgrade for the same total depth. The layered section should be checked to ensure that an adequate thickness of material is used to protect the underlying layer based upon the CBR of the underlying layer. The granular fill may consist of base and subbase material provided the top 6 inches meet the gradation requirements of paragraph 8.

6. Design CBR for select materials and subbases

Design CBR values and materials requirements for select materials and subbases are to be selected in accordance with TM 5-825-2 except as modified in table 4.



DESIGN CURVE FOR GRAVEL
SURFACED AIRFIELDS
CLASS I

Figure 2. Aggregate surfacing design curve for Class I airfields.

7. Frost area considerations

In areas where frost effects have an impact on the design of pavements, additional considerations concerning thicknesses and required layers in the pavement structure must be addressed. The specific areas where frost has an impact on the design are discussed in the following paragraphs; however, a more detailed discussion of frost effects is presented in TM 5-818-2. For frost design purposes, soils have been divided into eight groups as shown in table 5. Only the nonfrost-susceptible (NFS) group is suitable for base course. NFS, S1, or S2 soils may be used for subbase course, and any of the eight groups may be encountered as subgrade soils. Soils are listed in approximate order of decreasing bearing capability during periods of thaw.

a. Required thickness. Where frost susceptible subgrades are encountered, the section thickness required will be determined according to the reduced subgrade strength method. The reduced subgrade strength method requires the use of frost area soil support indexes listed in table 6. Frost-area soil support indexes are used as if they were CBR values; the term CBR is not applied to them, however, because, being weighted average values for an annual cycle, their values cannot be determined by CBR tests. Figures 1 through 4 are entered with the soil support indexes in place of CBR values to determine the required section thickness.

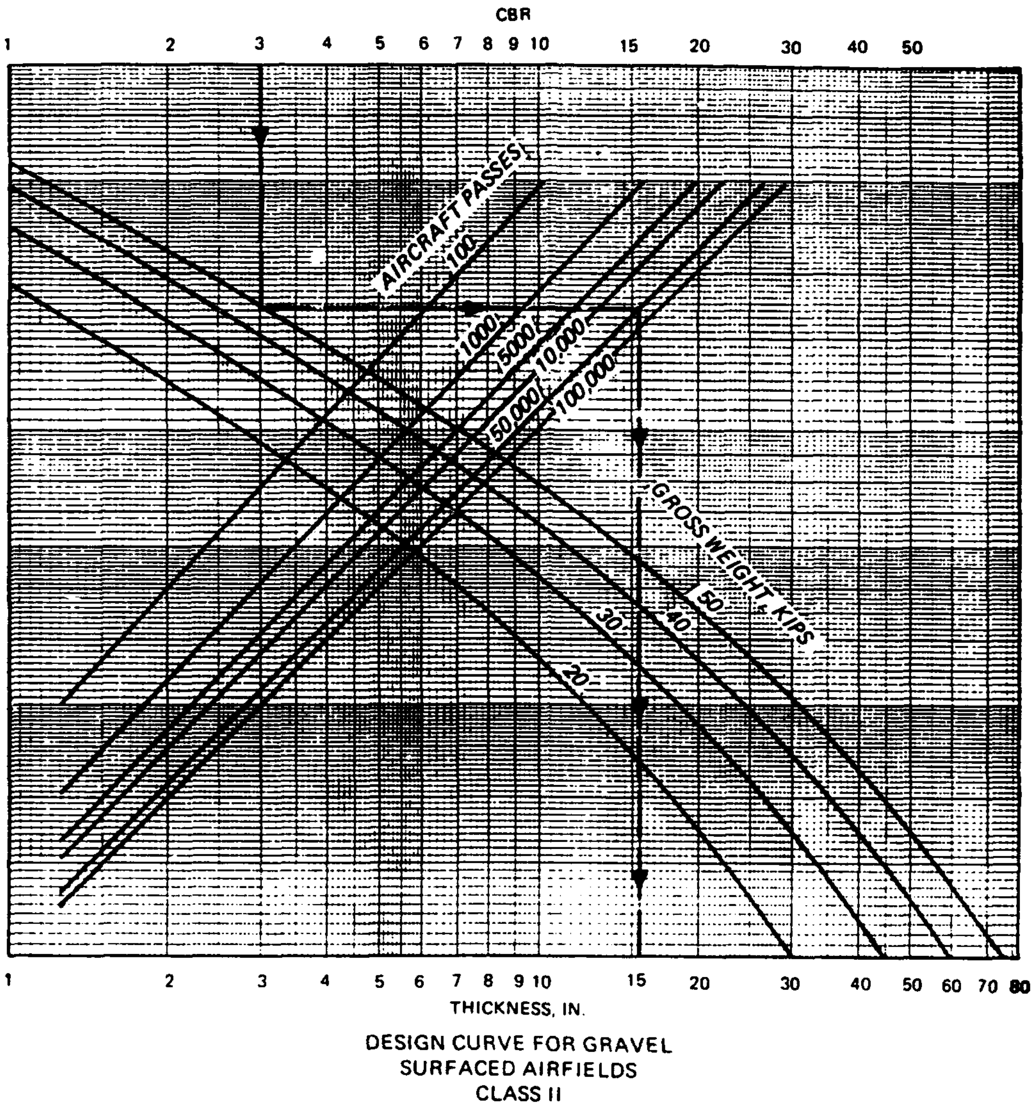


Figure 3. Aggregate surfacing design curve for Class II airfields.

b. Required layers in pavement section. When frost is a consideration, it is recommended that the pavement section consist of a series of layers that will ensure the stability of the system, particularly during thaw periods. The layered system in the aggregate fill may consist of a wearing surface of fine crushed stone, a coarse-graded base course, and/or a well-graded subbase of sand or gravelly sand. To ensure the stability of the wearing surface, the width of the base course and subbase should exceed the final desired surface width by a minimum of 1 foot on each side.

c. Wearing surface. The wearing surface contains fines to provide stability in the aggregate surface. The presence of fines helps the layer's compaction characteristics and helps to provide a relatively smooth riding surface.

d. Base course. The coarse-graded base course is important in providing drainage of the granular fill. It is also important that this material be nonfrost-susceptible so that it retains its strength during spring thaw periods.

e. Subbase. The well-graded sand subbase is used for additional bearing capacity over the frost-susceptible subgrade and as a filter layer between the coarse-graded base course and the subgrade to prevent the migration of the subgrade into the voids in the coarser material during periods of reduced subgrade strength. The material must therefore meet standard filter criteria.

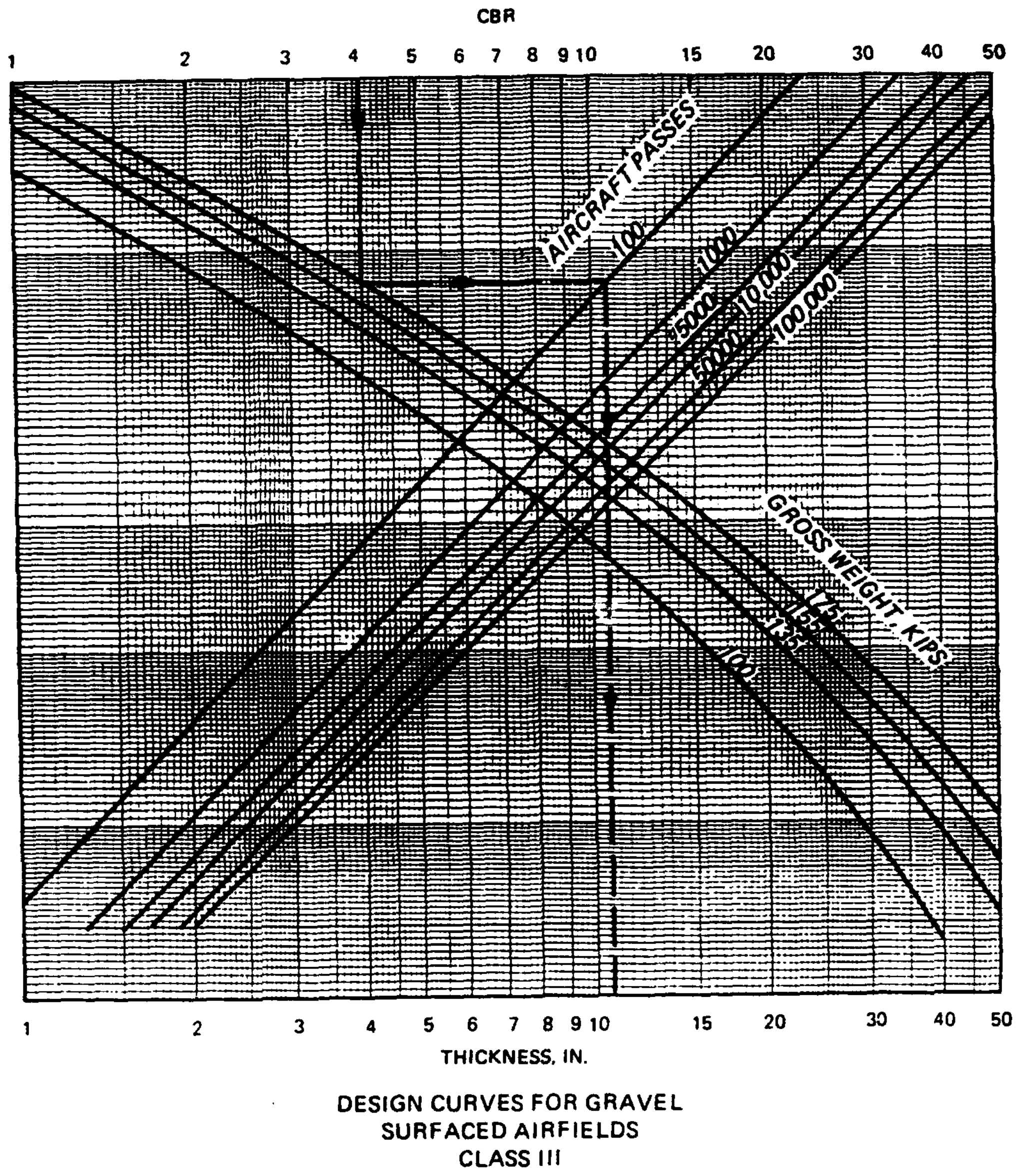


Figure 4. Aggregate surfacing design curve for Class III airfields.

The sand subbase must be either nonfrost-susceptible or of low frost susceptibility (S1 or S2). The filter layer may or may not be necessary depending upon the type of subgrade material. If the subgrade consists principally of gravel or sand, the filter layer may not be necessary and may be replaced by additional base course if the gradation of the base course is such that it meets filter criteria. However, for finer grained soils, the filter layer will be necessary. If a geotextile is used, the sand subbase/filter layer may be omitted as the fabric will be placed directly on the subgrade and will act as a filter.

f. Compaction. The subgrade should be compacted to provide uniformity of conditions and a firm working platform for placement and compaction of subbase. Compaction of subgrade will not change its frost-area soil support index, however, because frost action will cause the subgrade to revert to a weaker state. Hence, in frost areas, the compacted subgrade will not be considered part of the layered system of the road or airfield which should be comprised of only the wearing, base, and subbase courses.

g. Thickness of base course and filter layer. Relative thicknesses of the base course and filter layer are

Table 6. Maximum permissible values for subbases and select materials.

Material	Maximum Design CBR	Size inch	Gradation Requirements Percent Passing: No. 10 Sieve	Gradation Requirements Percent Passing: No. 200 Sieve	Liquid Limit*	Plasticity Index*
	Maximum Permissible Value					
Subbase	50	2	50	15	25	5
Subbase	40	2	80	15	25	5
Subbase	30	2	100	15	25	5
Select material	20	3	—	—	35	12

*Determinations of these values will be made in accordance with ASTM D 4318.

variable, and should be based on the required cover and economic considerations.

h. Alternate design. The reduced subgrade strength design procedure provides the thickness of soil required above a frost-susceptible subgrade to minimize frost heave. To provide a more economical design, a frost susceptible select material or subbase may be used as a part of the total thickness above the frost-susceptible subgrade. However, the thickness above the select material or subbase must be determined by using the FASSI of the select or subbase material. Where frost-susceptible soils are used as select materials or subbases, they must meet the requirements of current specifications except that the restriction on the allowable percent finer than 0.02 mm is waived.

8. Surface course requirements

The requirements for the various materials to be used in the construction of aggregate surfaced roads and airfields are dependent upon whether or not frost is a consideration in the design.

a. Nonfrost areas. The material used for gravel-surfaced roads and airfields should be sufficiently cohesive to resist abrasive action. It should have a liquid limit no greater than 35 and a plasticity index of 4 to 9. It should also be graded for maximum density and minimum volume of voids in order to enhance optimum moisture retention while resisting excessive water intrusion. The gradation, therefore, should consist of the optimum combination of coarse and fine aggregates that will ensure minimum void ratios and maximum density. Such a material will then exhibit cohesive strength as well as intergranular shear strength. Recommended gradations are as shown in table 7. If the fine fraction of the material does not meet plasticity characteristics, modification by addition of chemicals might be required. Chloride products can, in some cases, enhance moisture retention, and lime can be used to reduce excessive plasticity.

b. Frost areas. As previously stated, where frost is a consideration in the design of roads and airfields, a layered system should be used. The percentage of fines should be restricted in all the layers to facilitate drainage and reduce the loss of stability and strength during thaw periods. Gradation numbers 3 and 4 shown in table 7 should be used with caution since they may be unstable in a freeze-thaw environment.

9. Compaction requirements

Compaction requirements for the subgrade and granular layers are expressed as a percent of maximum CE 55 density as determined by using MIL-STD-621 Test Method 100. For the granular layers, the material will be compacted to 100 percent of the maximum CE 55 density. Select materials and subgrades in fills shall have densities equal to or greater than the values shown in tables 8 and 9 for roads and table 10 for airfields except that fills will be placed at no less than 95 percent compaction for cohesionless soils ($PI \leqq 5$; $LL \leqq 25$) or 90 percent compaction for cohesive soils ($PI > 5$; $LL > 25$). Subgrades in cuts shall have densities equal to or greater than the values shown in tables 8 through 10. Subgrades occurring in cut sections will be either compacted from the surface to meet the densities shown in tables 8 through 10, removed and replaced before applying the requirements for fills, or covered with sufficient material so that the uncompacted subgrade will be at a depth where the in-place densities are satisfactory. The depths shown in tables 8 through 10 are measured from the surface of the aggregate road or airfield and not the surface of the subgrade.

10. Drainage requirements

Adequate surface drainage should be provided in order to minimize moisture damage. Expeditious removal of surface water reduces the potential for absorption and ensures more consistent strength and reduced maintenance. Drainage, however, must be provided in a manner to preclude damage to the aggregate surfaced road or airfield through erosion of fines or erosion of the entire surface layer. Also, care must be taken to ensure that the change in the overall drainage regime as a result of construction can be accommodated by the surrounding topography without damage to the environment or to the newly constructed road or airfield.

a. The surface geometry of a road or airfield should be designed so that drainage is provided at all points. Depending upon the surrounding terrain, surface drainage of the roadway can be achieved by a continual cross slope or by a series of two or more interconnecting cross slopes. The entire area should consist of one or more cross slopes having a gradient that meet the requirements of TM 5-820-1 and TM 5-820-4. Judgement will be required to arrange the cross slopes in a manner to remove water from the road or airfield at the nearest

Table 5. Frost design soil classification.

Frost Group	Kind of Soil	Percentage Finer Than 0.02 mm by Weight	Typical Soil Types Under Unified Soil Classification System
NFS*	(a) Gravels Crushed stone Crushed rock	0-1.5	GW, GP
	(b) Sands	0-3	SW, SP
PFS**	(a) Gravels Crushed stone Crushed rock	1.5-3	GW, GP
	(b) Sands	3-10	SW, SP
S1	Gravelly soils	3-6	GW, GP, GW-GM, GP-GM
S2	Sandy soils	3-6	SW, SP, SW-SM, SP-SM
F1	Gravelly soils	6 to 10	GM, GW-GM, GP-GM
F2	(a) Gravelly soils (b) Sands	10 to 20 6 to 15	GM, GW-GM, GP-GM SM, SW-SM, SP-SM
F3	(a) Gravelly soils (b) Sands, except very fine silty sands (c) Clays, PI > 12	Over 20 Over 15 --	GM, GC SM, SC CL, CH
F4	(a) All silts (b) Very fine silty sands (c) Clays, PI < 12 (d) Varved clays and other fine-grained banded sediments	-- Over 15 -- --	ML, MH SM CL, CL-ML CL and ML CL, ML, and SM CL, CH, and ML CL, CH, ML and SM

*Nonfrost-susceptible.
**Possibly frost-susceptible, but requires laboratory test to determine frost design soil classification.

Table 6. Frost-area soil support indexes of subgrade soils.

Frost Group of Subgrade Soils	Frost Area Soil Support Index
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

possible points while taking advantage of the natural surface geometry to the greatest extent possible.

b. Adequate drainage must be provided outside the road or airfield area to accommodate maximum possible drainage flow from the road or airfield. Ditches and culverts will be provided for this purpose. Culverts should be used sparingly and only in areas where adequate cover of granular fill is provided over the culvert. Additionally, adjacent areas and their drainage

Table 7. Gradation for aggregate surface courses.

Sieve Designation		No. 1	No. 2	No. 3	No. 4
25.0 mm	1 in.	100	100	100	100
9.5 mm	3/8 in.	50–85	60–100	—	—
4.7 mm	No. 4	35–65	50–85	55–100	70–100
2.00 mm	No. 10	25–50	40–70	40–100	55–100
0.425 mm	No. 40	15–30	24–45	20–50	30–70
0.075 mm	No. 200	8–15	8–15	8–15	8–15

Note: The percent by weight finer than 0.02 mm shall not exceed 3 percent.

provisions should be evaluated to determine if rerouting is needed to prevent water from other areas flowing across the road or airfield.

c. Drainage is a critical factor in aggregate surface road or airfield design, construction, and maintenance. Therefore, drainage should be considered prior to construction, and when necessary, serve as a basis for site selection.

11. Maintenance requirements

The two primary causes of deterioration of aggregate surfaced roads requiring frequent maintenance are the environment and traffic. Rain or water flow will wash fines from the aggregate surface and reduce cohesion, while traffic action causes displacement of surface materials. Maintenance should be performed at least every 6 months and more frequently if required. The frequency of maintenance will be high for the first few years of use but will decrease over time to a constant value. The majority of the maintenance will consist of periodic grading to remove the ruts and potholes that will inevitably be created by the environment and traffic and to replace fines. Occasionally during the lifetime of the road or airfield, the surface layer may have to be scarified, additional aggregate added to increase the thickness back to that originally required, and the wearing surface recompacted to the specified density.

12. Dust control

a. Objective. The primary objective of a dust palliative is to prevent soil particles from becoming airborne as a result of wind or traffic. Where dust palliatives are considered for traffic areas, they must withstand the abrasion of the wheels or tracks. An important factor limiting the applicability of the dust palliative in traffic areas is the extent of surface rutting or abrasion that will occur under traffic. Some palliatives will tolerate deformations better than others, but normally ruts in excess of 1/2 inch will result in the virtual destruction of any thin layer or shallow-depth penetration dust palliative treatment. The abrasive action of tank tracks may be too severe for use of some dust palliatives in a traffic area.

b. A wide selection of materials for dust control is available to the engineer. No one choice, however, can be singled out as being the most universally acceptable for all problem situations that may be encountered. However, several materials have been recommended for use and are discussed in TM 5-830-3.

Table 8. Compaction requirements for roads, cohesive soils.

Percent Compaction	Depth of Compaction (in Inches) for Indicated Design Index: 1	2	3	4	5	6	7	8	9	10
100	2	3	3	3	4	4	4	5	5	6
95	4	5	5	6	7	7	8	9	10	11
90	6	7	8	9	10	11	12	13	15	17
85	7	9	10	12	13	15	16	18	20	22
80	9	11	13	14	16	18	20	22	25	27

Table 9. Compaction requirements for roads, cohesionless soils.

Percent Compaction	Depth of Compaction (in inches) for Indicated Design Index									
	1	2	3	4	5	6	7	8	9	10
100	4	5	5	6	7	7	8	9	10	11
95	7	8	10	11	12	14	15	17	19	21
90	10	12	14	16	18	20	22	24	28	30
85	13	16	18	21	23	26	29	31	35	38

Table 10. Compaction requirements for airfields.

Airfield Type	Traffic Area	Depth Below Pavement Surface, in.									
		Cohesive Soils, percent					Cohesionless Soils, percent				
		100	95	90	85	80	105	100	95	90	85
Class I	B	4	6	8	10	12	2	6	10	13	16
	C	3	5	7	9	10	1	5	8	11	14
Class II	B	5	8	12	15	19	2	8	14	21	26
	C	4	7	10	13	16	2	7	12	17	23
Class III	B	9	15	21	27	34	4	15	25	37	48
	C	7	12	17	22	29	3	12	21	31	41

13. Design examples No. 1. Assume the following conditions:

CBR values.

—Natural subgrade = 5 (CL material with PI = 15, Frost group F3).
—Compacted subgrade = 8.
—Fines graded crushed rock wearing surface = 80.

—Coarse graded crushed rock base course = 80.
—Clean sand subbase = 15.

Anticipated traffic.

—40 passes per day of 60-ton tracked vehicles.

Calculations:

a. From paragraph 4.d, select the traffic category for a 120,000-pounds tracked vehicle as Category VII.

b. The design index is then determined from table 3 to be 10 for 40 passes per day and Category VII traffic.

c. The required thickness of the tank trail is determined from figure 1. The following sections would be adequate if the natural subgrade has the required in-place density.

	7 inches crushed rock
17 inches crushed rock	10 inches sand subbase CBR = 15
Natural subgrade CBR = 5	Natural subgrade CBR = 5

d. Where the subgrade is compacted to a CBR of 8, the following sections would be *satisfactory:*

12 inches crushed rock	7 inches crushed rock
	5 inches sand subbase CBR = 15
5 inches compacted subgrade CBR = 8	5 inches compacted subgrade CBR = 8
Natural subgrade CBR = 5	Natural subgrade CBR = 5

e. In areas where frost is not a factor in the design of roads, the sections shown above are adequate, and the most economical should be used. The granular material should conform to the material requirements for nonfrost areas previously discussed. If available, subbase materials other than the clean sand may be used for adjusting the sections.

f. Determine the surface geometry of the tank trail in a severely cold area where subgrade freezing is predicted.

g. In areas where frost is a consideration, the tank trail should consist of the following layers:

—A wearing surface of fine-graded crushed rock.
—A base course of coarse-graded crushed rock.
—A subbase of well-graded sand, frost group soils F1 and F2, or geotextile.

As previously stated, the function of the last layer as a filter layer is not always required, depending upon the subgrade material. In this case the subgrade is a CL; therefore, it is required. According to table 6, the frost-area soil support index for an F3 subgrade soil is 3.5. With the exception of the wearing surface layer which will vary between 4 and 6 inches, the other layers are varied based on economic factors. However, the required thickness of cover over the various layers must be satisfied. Also, the minimum thickness of each layer should be 4 inches.

h. Possible alternatives for the tank trail section based on frost considerations might be:

(1) Using sand subbase. From figure 1 using a frost-area soil support index of 3.5 and a design index of 10, the total thickness required above the subgrade equals 21.0 inches. Also from figure 1, the minimum required cover over the NFS, S1, or S2 sand subbase (CBR = 15) is 7.0 inches. Using a minimum layer thickness of 4 inches in the wearing surface and the course graded base course, the actual cover required will be 8 inches. Therefore, the section might be:

4 inches fine-graded stone
4 inches coarse-graded crushed stone
13 inches well-graded sand subbase (CBR = 15)
Subgrade

(2) An alternative section might be to construct the wearing course and subbase to a minimum thickness of 4 inches.

4 inches fine-graded stone
13 inches coarse-graded crushed stone
4 inches well-graded sand subbase
Subgrade

(3) Using F1 and F2 soils. As previously stated. frost group soils F1 and F2 may be used in the lower part of the granular material over F3 and F4 subgrade soils. The thickness of F2 base material should not exceed the difference between the thickness required over F3 and the thickness required over an F2 subgrade. The minimum required cover over F1 soils is 11 inches, over F2 soils is 14 inches, and over F3 soils is 21 inches. Using a minimum layer thickness of 4 inches, the following section may be used:

4 inches fine-graded stone
7 inches coarse-graded crushed stone
4 inches frost group soil F1
6 inches frost group soil F2
Subgrade - F3

For economy, based on material availability, these sections may be altered as long as a higher-quality material is used above a lesser-quality material. For example. crushed stone could be substituted for the F1 soil.

(4) Using geotextiles. Either of the designs shown above could be used by deducting 6 inches of well-graded sand subbase and replacing it with a geotextile. The total thickness above the geotextile must be a minimum of 15 inches. Alternative designs using a geotextile might be:

4 inches fine-graded stone
11 inches coarse-graded crushed stone
geotextile
Subgrade

or:

7 inches fine-graded stone
8 inches well-graded sand
geotextile
Subgrade

Notes:

—All layer depths should be rounded up to the next full inch for construction purposes.

—The granular layers should be compacted to 100 percent CE 55 maximum density.

—The subgrade should be compacted to the density required by table 8.

—The material should meet the gradation requirements shown herein.

—The frost group soils F1 and F2 used as base and subbase materials should meet the requirements in the appropriate guide specifications.

—As previously stated, after all possible design sections are determined, the final section used for the tank trail should be determined on the basis of an economic analysis.

14. Design Example No. 2. Assume the following conditions:

CBR values.

—Natural subgrade = 4 (SM – silty sand material, frost group F2).

—Compacted subgrade = 8.

—Fine-graded crushed rock wearing surface = 80.

—Course-graded crushed rock base course = 80.

—Clean sand subbase = 15.

Projected traffic.

—2,500 operations per day of Category IV traffic.

Calculations:

a. Determine the required thickness. From table 1 determine the road to be a Class D road. From table 3, select a design index = 5. From the design curves (figure 1) the required thickness above the natural subgrade with a CBR of 4 is 11.5 inches (round to next full inch of 12); the required cover over the compacted subgrade (CBR = 8) is 7 inches. Therefore, the hardstand might have the following cross sections:

12.0 inches crushed rock	4 inches crushed rock	7 inches crushed rock
	8.0 inches sand subbase	Compacted subgrade CBR = 8
Subgrade CBR = 4	Subgrade CBR = 4	

b. Determine the cross section in a severely cold area where subgrade freezing is predicted.

(1) Only the wearing surface and base course layers will apply in this section. The sand subbase is not required because the subgrade is not cohesive. The filter fabric will not be used because the subgrade soil is an F2 material and the use of this fabric is restricted to F3 and F4 subgrade soils.

(2) In this case the natural subgrade CBR of 4 is less than the frost-area soil support index and will govern the design. The total thickness required above a subgrade CBR = 4 is 12.0 inches.

(3) Therefore, the cross section for this condition will be:

4 inches fine-graded stone
8.0 inches coarse-graded crushed stone
Subgrade CBR = 4

c. Based on economic considerations, alternative sections may be developed using frost group soils S1, S2, and F1 with lower portion of the base material. An example using F1 soils is as follows:

7.0 inches fine-graded stone
5 inches frost group soil F1
Subgrade CBR = 4

15. Design Example No. 3. Assume the following conditions:

Design is for Army Class III airfield.

Traffic protection = 10,000 passes of C-130 aircraft.

Design gross weight = 135 kips.

CBR values.

—Subgrade = 6

—Crushed stone = 80

Enter figure 4 with the subgrade CBR of 6, the 135 kip gross weight and 10,000 passes, and read the thickness required above the 6 CBR of 13.5 inches which when rounded to the next full inch will be 14.0 inches. The section therefore would be:

14.0 inches of crushed stone
Subgrade CBR = 6

APPENDIX A
REFERENCES

Government Publications

Department of Defense

MIL-STD-621A, Notices 1, 2	Test Method for Pavement Subgrade, Subbase, and Base-Course Materials

Departments of the Army, Navy, and Air Force

TM 5-803-4	Planning of Army Aviation Facilities
TM 5-818-2	Pavement Design of Seasonal Frost Areas
TM 5-820-1/AFM 88-5, Chap. 1	Surface Drainage Facilities for Airfields and Heliports
TM 5-820-4/AFM 88-5, Chap. 4	Drainage for Areas Other Than Airfields
TM 5-822-2/AFM 88-7, Chap. 5	General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas
TM 5-822-5/AFM 88-7, Chap. 3	Flexible Pavements for Roads, Streets, Walks and Open Storage Areas
TM 5-825-2/AFM 86-6, Chap. 2/ NAVFAC DM 21.3	Flexible Pavement Design for Airfields
TM 5-830-3	Dust Control for Roads, Airfields, and Adjacent Areas

Nongovernment Publications

American Society for Testing and Materials (ASTM): 1916 Race Street, Philadelphia, PA 19103

D 4318-83	Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

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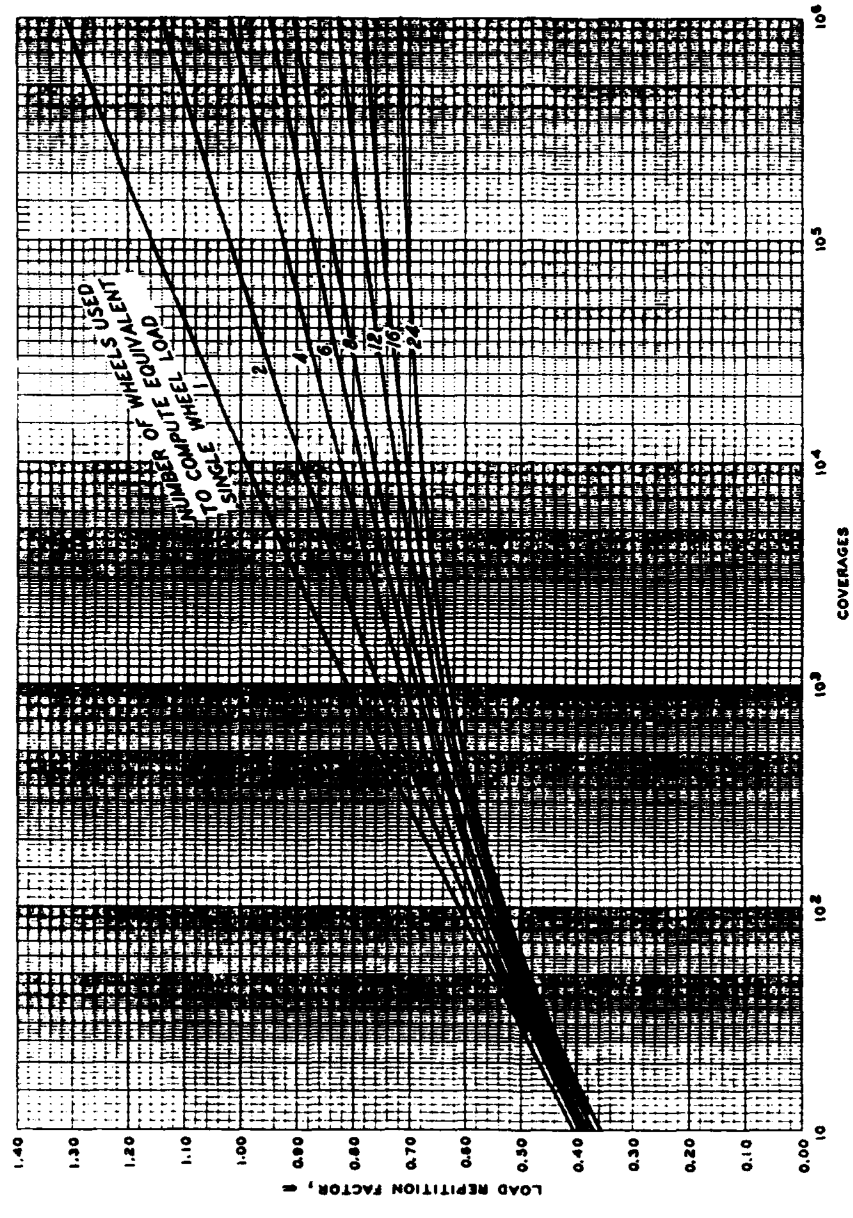

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